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Ensilage performance of sorghum hybrids varying in extractable sugars

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Abstract

Renewable feedstock resources require novel storage technologies to optimize industrial use. Solid state fermentation of biomass feedstock may provide organic chemicals and fibers while reducing the risk of current dry-storage procedures. Here, we compare the chemical composition and fermentation of six sorghum hybrids (*Sorghum bicolor* L. Moench) following 1, 7, and 21 days of storage. Ensilage of 7 days resulted in a pH of 3.8 and declined further to 3.75 at day 21. Lactate increased during ensilage from 2.0 to $3.9\,g\,100\,g^{-1}$. Acetic acid increased between 1 and 7 days of ensiling but did not change until the end of the ensiling period. Total organic acids averaged $2.5\,g\,100\,g^{-1}$ after day 1 and increased to 4.2 and $4.7\,g\,‘100\,g^{-1}$ after days 7 and 21, respectively. Neutral detergent fiber ranged from 38 to $50\,g\,100\,g^{-1}$ among hybrids and total non-structural carbohydrates varied from 18 to $32\,g\,100\,g^{-1}$. Hemicellulose and cellulose ranged from 13 to $19\,g\,100\,g^{-1}$ and 20 and $28\,g\,100\,g^{-1}$, respectively. Genotypic variation in sorghum may offer designing dual-purpose hybrids for production of biomass and economically valuable byproducts.

Keywords: *Sorghum bicolor* (L.); Solid state fermentation; Chemical composition

1. Introduction

The impact of storage on feedstock characteristics of renewable resources is critical to understanding potential fuel and fiber production. Currently, dry storage procedures are used to minimize decomposition, but have the inherent risk of fire from either spontaneous or accidental combustion. Ensilage procedures decrease the risk of fire. Moreover, silage technologies may provide additional benefits for industrial products such as ethanol, chemicals, and fiberboard [1]. These technologies have been used in the past in agriculture to preserve animal feed and may be applicable to preserve biofeedstock. The goal of ensiling plant materials is to prevent deterioration by rapid lactic acid fermentation under anaerobic conditions, to conserve cellulosic materials and minimize carbohydrate degradation. Conversely, where oxygen is in contact with herbage during storage, aerobic activity may decay the material to useless and even toxic products [2].

Sorghum (*Sorghum bicolor* L. Moench) has been used widely as an agricultural feedstock, predominantly to produce ethanol through solid state fermentation. Worldwide, about 10 Tg of sorghum straw would be available as a biomass feedstock. Also, lignin-rich fermentation residues could generate 3.7 TWh of electricity and 21 PJ of superheated steam [3]. Globally, wasted sorghum grain and sorghum straw could produce $4.9\,hm^3$ of bioethanol.

Some characteristics that may make sorghum more suitable than corn (*Zea mays* L.) are its higher drought resistance and higher starch content [4]. Other researchers [5] acknowledged the importance of breeding new varieties of sweet sorghum to increase stem sugar content, with the objective to produce derivatives usable as fuel. These authors indicated that 1 t fresh sorghum biomass yielded 489 kg of fresh juice that could be converted to 32 kg of

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ethanol. Additionally, the energy needed to produce 1 t of sweet sorghum may be low compared with corn, rice (*Oryza sativa* L.), or sugarcane (*Saccharum officinarum* L.). However, others [6] suggested that the potential return of ensiled sorghum stalks were below that of baled switchgrass (*Panicum virgatum* L.), and, thus, ensiling sorghum may not be economically feasible.

Carbohydrate concentration in plant material is crucial as it influences rapid acidification [7]. Several sweet sorghum varieties have been developed and released more recently, including Della [8], Smith [9], and Grassl [10]. Thus, the objective of this study was to determine variability in ensiling quality parameters in sorghum hybrids differing in sugar content.

2. Materials and methods

Six sorghum hybrids with differing sugar content were used in this investigation (Table 1). N98 was derived from an initial cross of an experimental cytoplasmic male-sterile R-line to Waconia sweet sorghum, followed by a final cross to 'Fremont' forage sorghum [11]. N109 and N110 were cytoplasmic male-sterile A-lines developed for use as female lines for sweet sorghum hybrids. The lines IS 12524C, IS 6414C, and IS12558C originated in Ethiopia and India, respectively, are short statured and photoperiod insensitive, and were released in 1986 by the USDA-ARS/Texas A&M sorghum conversion program in Puerto Rico [12].

The hybrids were planted on May 21 1991, on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll) at the University of Nebraska Agricultural and Development Center near Ithaca, NE (96°33′W, 41°11′N) in plots two rows wide and 7.6 m long on 0.76 m centers. All plots were fertilized with 112 kg N ha^{-1} prior to planting, and treated with 3.75 kg ha^{-1} Ramrod® (propachlor; Monsanto, St. Louis, MO) and 1.25 kg ha^{-1} atrazine (2-chloro-4-ethylamine-6-isopropylamino-S-triazine; Monsanto, St. Louis, MO) immediately following planting. No irrigation was applied. Samples were harvested in September 13 1991 at soft dough stage. Total precipitation from May to September was 513 mm and average temperature of 21.7 °C.

Each plot was harvested and sorghum was chopped to a length of 1 cm with a commercial silage cutter. Bulked fresh chopped forage was immediately transported to the laboratory in plastic bags and placed in containers with a volume of 20 l. The forage was packed tightly into double-lined plastic bags inside the containers and air was evacuated from the silage by vacuum prior to ensiling to prevent possible aerobic deterioration of samples.

Table 1
Pedigrees and percent Brix of sorghum hybrids grown at Ithaca, NE in 1991

Hybrid	Pedigree	Brix (%)
1	AN109 × IS12524C	10.5
2	AN110 × IS6414C	10.7
3	AN110 × N98	16.3
4	AN109 × N98	18.4
5	AN109 × IS6414C	10.8
6	AN110 × IS12558C	12.0

Silage samples were collected following 0, 1, 7, and 21 days of ensiling and analyzed for dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), hemicellulose, and cellulose [13]. Total non-structural carbohydrates (TNC) [14], water soluble carbohydrate (WSC) and total N were also quantified [15]. Additionally, juices were extracted from each sample to determine NH_3, pH, acetic acid, propionic acid, butyric acid, and lactic acid concentration [16]. Concentration of each chemical component was based on DM present in the original silage sample. Total organic acids (TOA) were calculated as the sum of acetic acid, propionic acid, butyric acid, and lactic acid.

The experimental design was a completely randomized design with four replications. Data were analyzed for effects of hybrid, time, and hybrid by time interaction using the Proc GLM procedure of SAS [17]. Differences are considered to be significant if $P<0.05$ unless stated otherwise.

3. Results

3.1. Chemical composition

Concentrations of ADF, ADL, N, and DM did not interact with ensilage length and were thus averaged across time (Table 2). Although a hybrid by time interaction was found to be significant for NDF, this quantity is presented in the same format (Table 2), because observed interaction appeared to be caused by differences in magnitude of response only and not by differences in direction of response. Our results suggested that fiber concentrations were greater in either hybrid 1 or 2 than in hybrids 3–6.

Cellulose concentrations (Fig. 1) remained approximately between 20 and 30 g 100 g^{-1} throughout the experiment. Differences in hemicellulose concentrations among hybrids appeared to be greater at day 21 than during previous sampling dates (Fig. 2). Concentrations of WSC during ensilage reflected the percent Brix content of the hybrids used in the experiment (Fig. 3).

3.2. Fermentation

Data for pH, lactic acid, and TOA were displayed with respect to their temporal change across time of ensilage, although a hybrid by time interaction was present only in pH. Time and hybrid effects were observed in all of these dependent variables.

Hybrid 6 had lower pH than hybrids 1, 2, 4, and 5 after 1 day of ensiling (Fig. 4). Maximum pH was observed in hybrid 2. Values were reduced after 7 days of fermentation.

Table 2
Chemical composition of sorghum hybrids after ensiling, averaged across time of ensiling (0, 1, 7, and 21 days)

Variable†	Hybrid* ($g\,100\,g^{-1}$)						SE‡
	1	2	3	4	5	6	
DM	46.3^{a}	32.8^{c}	32.3^{c}	32.7^{c}	37.1^{b}	36.6^{c}	0.6
NDF§	49.8^{a}	50.4^{a}	37.9^{c}	39.1^{c}	44.7^{b}	44.7^{b}	1.7
ADF	30.7^{b}	33.6^{a}	24.6^{d}	25.3^{d}	26.9d^{c}	28.1^{c}	0.8
ADL	5.4^{a}	5.9^{a}	4.3^{b}	4.4^{b}	4.2^{b}	4.5^{b}	0.3
N	1.3^{a}	1.1^{b}	0.8^{c}	1.1^{b}	1.1^{b}	0.8^{c}	0.03

*See Table 1.
†DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; N = nitrogen.
‡SE = standard error of the mean.
§Hybrid by time interaction present ($P<0.05$).
Means denoted with the same letter within a variable are not different ($P>0.05$).

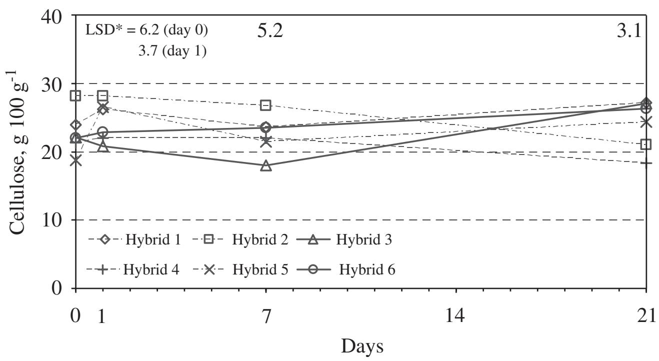

Fig. 1. Cellulose concentration of 6 sorghum hybrids ensiled for 0, 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

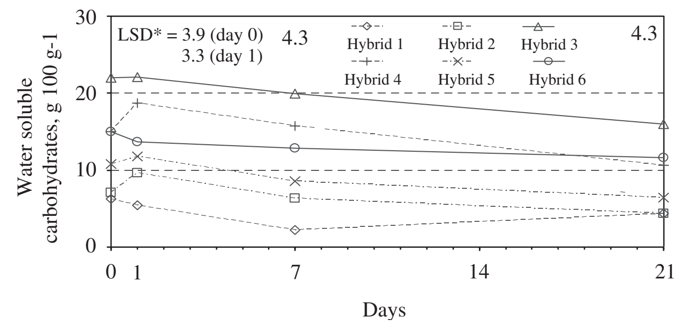

Fig. 3. Water soluble carbohydrate concentration of 6 sorghum hybrids ensiled for 0, 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

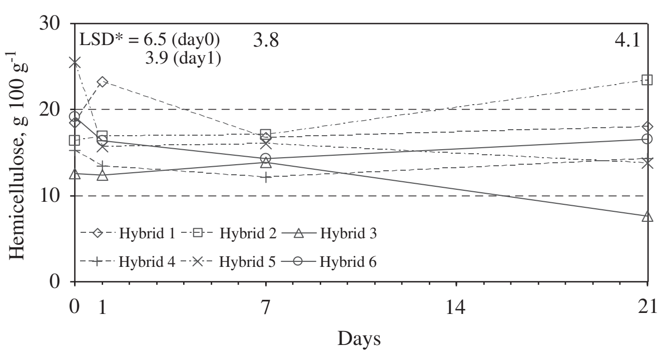

Fig. 2. Hemicellulose concentration of 6 sorghum hybrids ensiled for 0, 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

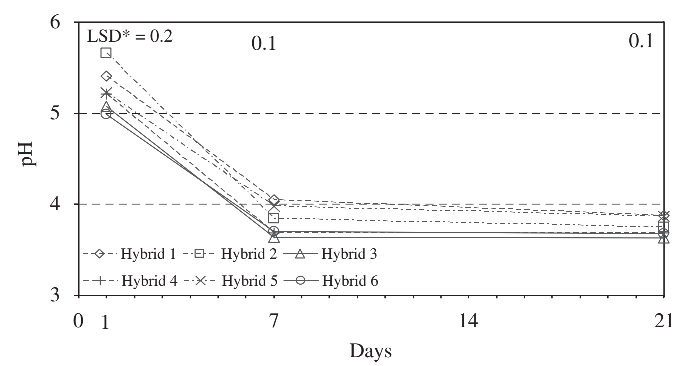

Fig. 4. The pH of 6 sorghum hybrids ensiled for 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

Hybrid 2 was lower in pH than in hybrids 1 and 5. In general, the range of pH values among hybrids appeared to be smaller with proceeding ensiling time. After 21 days, minimum values of pH was observed in hybrid 3 that was lower than is hybrids 1, 2 and 5. Averaged across hybrids, pH values were reduced from 5.3 at day 1 to 3.8 at day 21.

Maximum concentrations of lactic acid after day 1 were observed in hybrid 3 that were higher than hybrids 1, 4, and 5 (Fig. 5). Sorghum hybrids averaged $2.05\,g\,100\,g^{-1}$ after 1 day of ensilage but increased to about 3.4 after 7 days and increased further to $3.9\,g\,100\,g^{-1}$ after 21 days. After 7 days of ensiling, hybrid 3 was higher in lactate than hybrid 5. Similar findings were made after 21 days. Lactic acid concentrations averaged across hybrids increased from day 1 to day 7 and day 21.

Total organic acids averaged across hybrids $2.5\,g\,100\,g^{-1}$ after 1 day of ensiling and increased to 4.2 and $4.7\,g\,100\,g^{-1}$ after 7 and 21 days, respectively. One day after ensiling acids, hybrid 3 were higher than is hybrids 1, 4, and 5

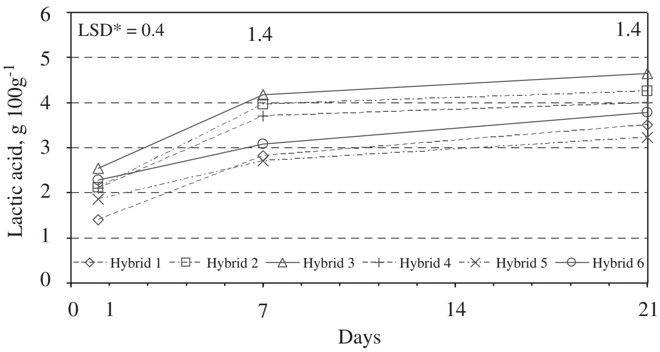

Fig. 5. Lactic acid concentration of 6 sorghum hybrids ensiled for 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

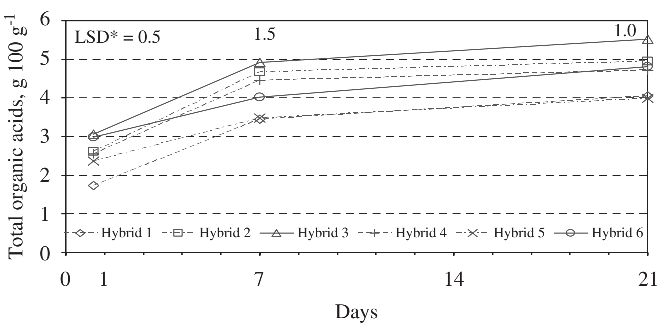

Fig. 6. Total organic acid concentration of 6 sorghum hybrids ensiled for 1, 7, and 21 days. *LSD = least significant difference ($\alpha = 0.05$).

(Fig. 6). No differences were observed among hybrids after a 7-day period. However, after 21 days hybrid 3 was again higher in TOA than hybrids 1 and 5, but similar to hybrids 2, 4, and 6.

4. Discussion

Our data demonstrate that differences among sorghum hybrids exist regarding fermentation potential. This may influence potential use and the economics of sorghum as bioenergy feedstock. Variation in chemical composition among the tested sorghum hybrids appeared large enough to select for lines according to industrial requirements. Cell wall concentration varied by about 25% among sorghum hybrids, whereas cellulose and hemicellulose varied by approximately 30%, respectively. Water soluble carbohydrate concentrations among hybrids followed tendencies contrary to those of NDF and varied by about 75%. Hybrids with higher amounts of WSC also resulted in higher amounts of TOA and lower pH.

Sorghum as a dual-purpose crop may have advantages in semi-arid areas of the US where limited water resources make less irrigation dependence necessary [18]. Compared with corn, sorghum has greater ability to recover from drought and higher yield potential under dryland conditions [19]. In 1996, sorghum was grown on approximately 53,000 km^2, predominantly in the Great Plains. Dryland grain yields averaged 3.8 $Mg\,ha^{-1}$ during the 1990s on a location in the Southern High Plains of Texas [20]. Cultivation of sorghum in these semi-arid areas may also provide opportunities for intercropping depending on availability of soil water. Research conducted in the Texas High Plains suggested that sorghum yields may range from 1.2 to 9.2 $Mg\,ha^{-1}$, depending on soil moisture [21]. Sorghum was planted whenever soil became wetted by precipitation to at least a 0.6 m depth after a main crop was harvested. Thus, occasional intercropping may provide farmers not only with additional income in general, but the use of specific sorghum hybrids may enhance the flexibility to adjust their systems to either sorghum biomass or grain production.

Hindering the development of sorghum as a biomass crop could be the immense variability among hybrids [22] as also shown in our investigation, and further research may be necessary to develop hybrids that provide either sufficient grain yield or biomass. Grain sorghum varieties may be short in height to prevent lodging, thus, may not generate sufficient biomass. Furthermore, the DM content in many cases may be below ideal ranges ($<300\,g\,kg^{-1}$) for ensiling [1]. Our data show that 4 out of 6 hybrids tested were only slightly higher in DM than 300 $g\,kg^{-1}$. Also, research on hay-type sorghum species suggested that between 1950 and 2000 stem and leaf crude protein (CP) decreased and leaf NDF increased [22]. For use as bioenergy feedstock, high fiber concentrations may be advantageous, although high cell soluble concentrations may help to produce appreciable amounts of organic acids. For an increase in cell soluble concentration, some authors suggested that the most rapid genetic gain in sorghum fermentation quality could be made by selecting for increased IVDMD in fresh dried sorghum [23,24].

In conclusion, genotypic variation in sorghum composition offers the potential of developing hybrids that are specifically designed for biomass end uses and also for developing dual-purpose hybrids that could be used for both grain and biomass. Solid-state fermentation has the potential as a low cost and low risk technology for preserving biomass as well as for producing potentially valuable co-products.

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